Embodied Cognition as a Framework for External Representations to Teach Science

Niebert, Kai

Embodied Cognition as a **Framework** for **External Representations** to **Teach Science**

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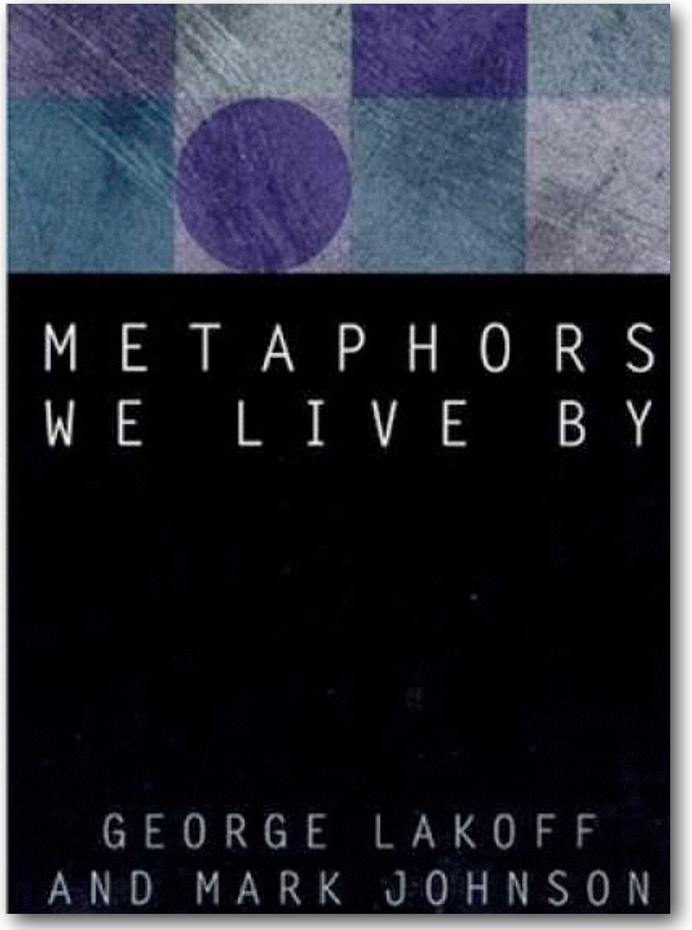
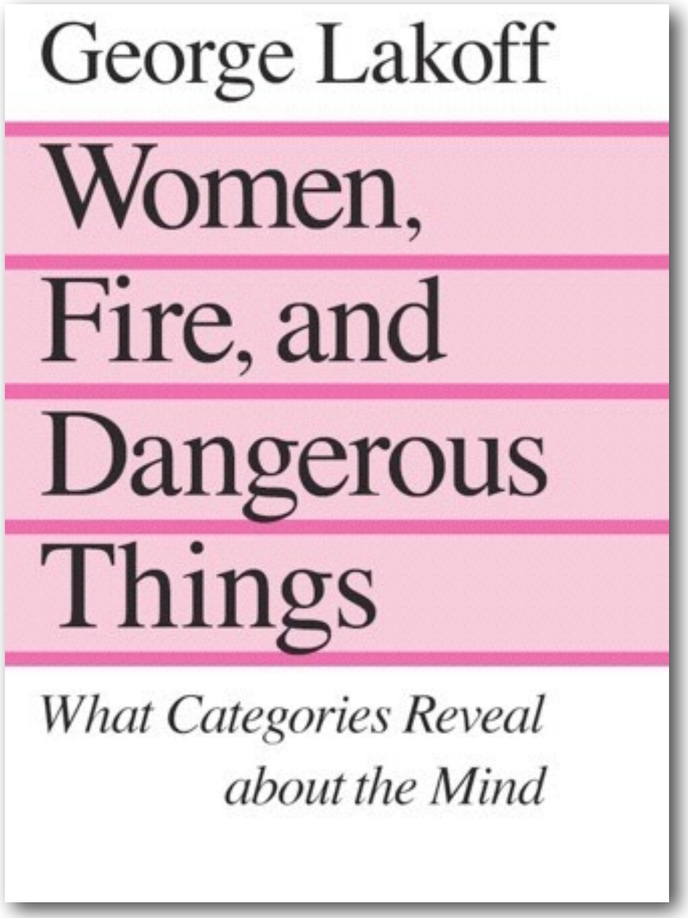
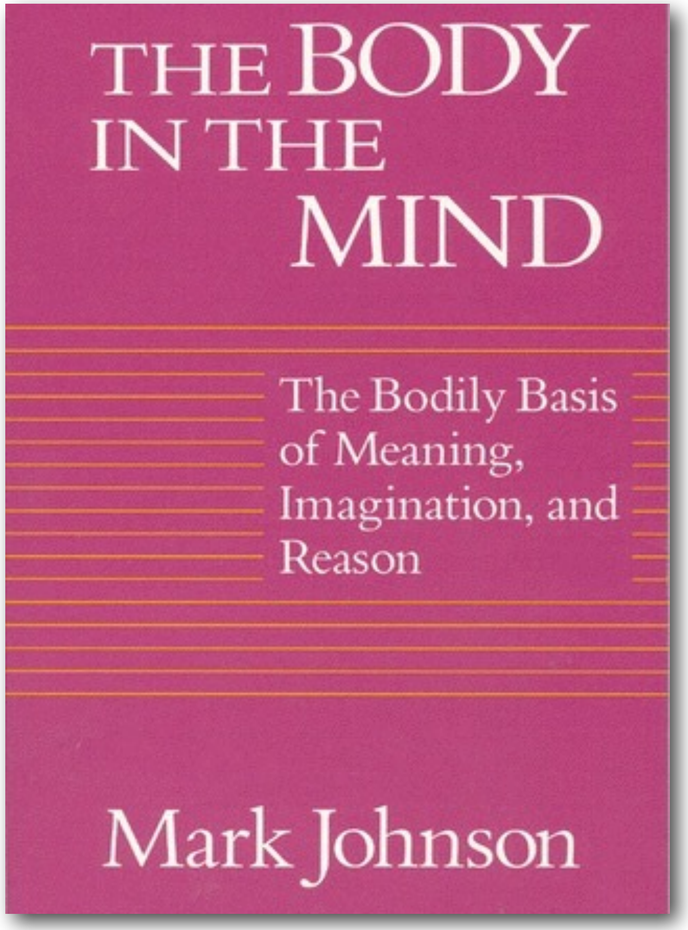

METAPHORS
WE LIVE BY
GEORGE LAKOFF
AND MARK JOHNSON


George Lakoff
Women,
Fire, and
Dangerous
Things
What Categories Reveal
about the Mind


THE BODY
IN THE
MIND
The Bodily Basis
of Meaning,
Imagination, and
Reason
Mark Johnson

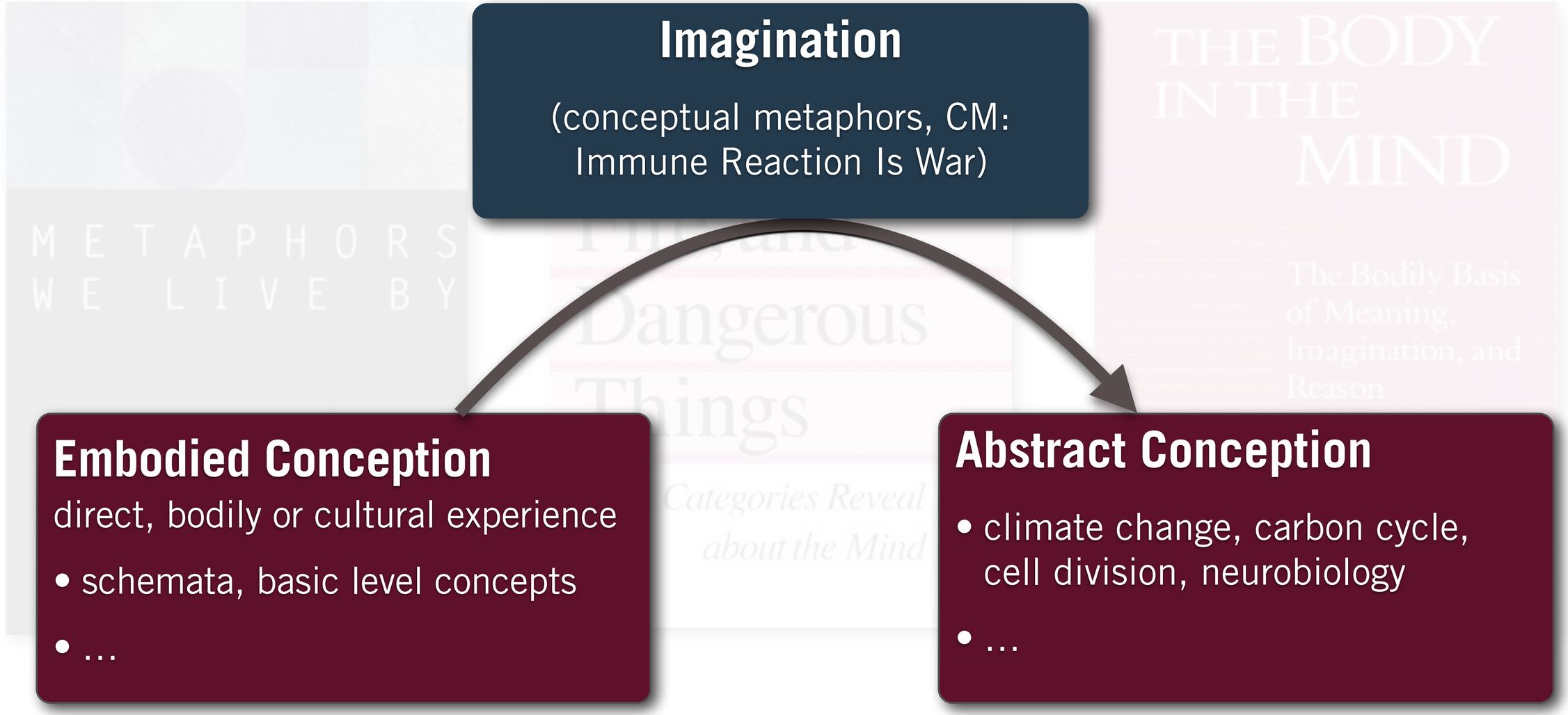
Understanding is embodied

Embodied Conception

Embodied conceptions arise out of perception, body movement, and experience with the physical and social environment.

Abstract Conception

For concepts, which cannot be experienced directly we need to think imaginatively to understand.


Imagination
(conceptual metaphors, CM: Immune Reaction Is War)
Embodied Conception
direct, bodily or cultural experience
• schemata, basic level concepts
• …
Abstract Conception
• climate change, carbon cycle, cell division, neurobiology
• …

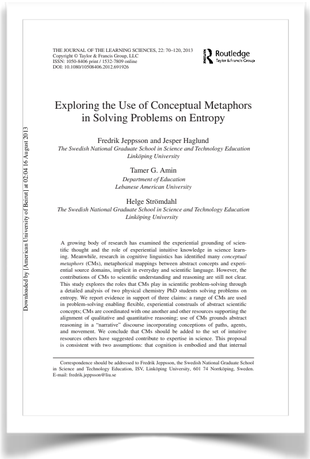
BOUNDARIES OF THE MESOCOSM

Microcosm ⟵ **Mesocosm** ⟶ **Macrocosm**

	Lower boundary	*Upper boundary*
Time	 ***seconds*** *(heartbeat)*	***decades*** *(lifetime)* 
Range	 ***millimetre*** *(hair: 0,1 mm)*	***kilometre*** *(horizon: 20 km)* 
Speed	 ***v = 0*** *(rest)*	***v = 10 m/s*** *(runner)* 
Acceleration	 ***a = 0*** *(steady motion)*	***a = 10 m/s2*** *(runner)* 
Weight	 ***gram*** *(ping-pong ball)*	***ton*** *(tree, elephant, rock)* 
Temperature	 ***0 °C*** *(freezing point)*	***100 °C*** *(boiling of water)* 

see also: Vollmer, G. (1984).
Mesocosm and objective knowledge.

EMBODIED UNDERSTANDING OF SCIENCE CONCEPTS



THE JOURNAL OF THE LEARNING SCIENCES, 22: 70–120, 2013
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ISSN: 1050-8406 print / 1532-7809 online
DOI: 10.1080/10508406.2012.691926

Exploring the Use of Conceptual Metaphors in Solving Problems on Entropy

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A growing body of research has examined the experiential grounding of scientific thought and the role of experiential intuitive knowledge in science learning. Meanwhile, research in cognitive linguistics has identified many *conceptual metaphors* (CMs), metaphorical mappings between abstract concepts and experiential source domains, implicit in everyday and scientific language. However, the contributions of CMs to scientific understanding and reasoning are still not clear. This study explores the roles that CMs play in scientific problem-solving through a detailed analysis of two physical chemistry PhD students solving problems on entropy. We report evidence in support of three claims: a range of CMs are used in problem-solving enabling flexible, experiential construals of abstract scientific concepts; CMs are coordinated with one another and other resources supporting the alignment of qualitative and quantitative reasoning; use of CMs grounds abstract reasoning in a "narrative" discourse incorporating conceptions of paths, agents, and movement. We conclude that CMs should be added to the set of intuitive resources others have suggested contribute to expertise in science. This proposal is consistent with two assumptions: that cognition is embodied and that internal

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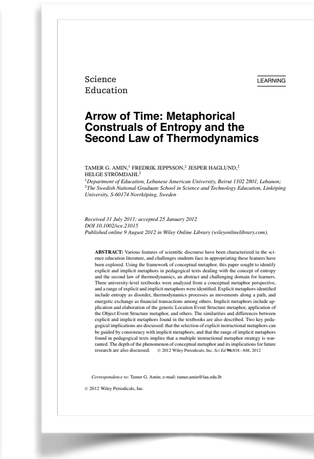

Science Education

LEARNING

Arrow of Time: Metaphorical Construals of Entropy and the Second Law of Thermodynamics

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Received 31 July 2011; accepted 25 January 2012
DOI 10.1002/sce.21013
Published online 9 August 2012 in Wiley Online Library (wileyonlinelibrary.com).

ABSTRACT: Various features of scientific discourse have been characterized in the science education literature, and challenges students face in appropriating these features have been identified. Drawing on the cognitive linguistic framework of conceptual metaphor theory, explicit and implicit reasoning metaphors in a typical texts dealing with the concept of entropy and the second law of thermodynamics, an abstract and challenging domain for learners. Three university-level textbooks were analyzed from a conceptual metaphor perspective, and a range of explicit and implicit metaphors were identified. Explicit metaphors identified include entropy as disorder, thermodynamics processes as movements along a path, and energetic exchange as financial transactions among others. Implicit metaphors include application and elaboration of the generic Location Event Structure metaphor, application of the Object Event Structure metaphor, and others. The similarities and differences between the two kinds of metaphors are discussed, and the role of each kind in learning is clarified. Pedagogical implications are discussed; that the selection of explicit instructional metaphors can be guided by consistency with implicit metaphors; and that the range of implicit metaphors found in pedagogical texts implies that a multiple instructional metaphor strategy is warranted. The depth of the phenomenon of conceptual metaphor and its implications for future research are also discussed. © 2012 Wiley Periodicals, Inc. Sci Ed 96:1–28, 2012

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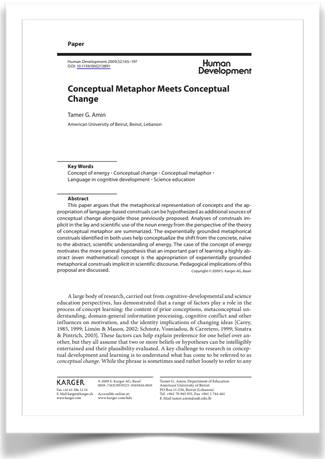

Paper

Human Development 2009;52:165–197
DOI: 10.1159/000213951

Human Development

Conceptual Metaphor Meets Conceptual Change

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American University of Beirut, Beirut, Lebanon

Key Words
Concept of energy · Conceptual change · Conceptual metaphor · Language in cognitive development · Science education

Abstract
This paper argues that the metaphorical representation of concepts and the appropriation of language-based construals can be hypothesized as additional sources of conceptual change alongside those previously proposed. Analyses of construals implicit in the lay and scientific use of the noun *energy* from the perspective of the theory of conceptual metaphor are summarized. The experientially grounded metaphorical construals identified in both uses help conceptualize the shift from the concrete, naive to the abstract, scientific understanding of energy. The case of the concept of energy motivates the more general hypothesis that an important part of learning a highly abstract (even mathematical) concept is the appropriation of experientially grounded metaphorical construals implicit in scientific discourse. Pedagogical implications of this proposal are discussed.

A large body of research, carried out from cognitive-developmental and science education perspectives, has demonstrated that a range of factors play a role in the process of conceptual learning. The content of prior conceptions, metaconceptual understanding, domain-general information processing, cognitive conflict and other influences on motivation, and the identity implications of changing ideas (Carey, 1985, 1999; Limón & Mason, 2002; Schoster, Vosniadou, & Carretero, 1999; Sinatra & Pintrich, 2003). These factors can help explain preference for one belief over another, but they all assume that two or more beliefs or hypotheses can be intelligibly entertained and their plausibility evaluated. A key challenge to research in conceptual development and learning is to understand what has come to be referred to as *conceptual change*. While the phrase is sometimes used rather loosely to refer to any

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Environmental Education Research
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ceer20

Understanding and communicating climate change in metaphors

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Available online: 19 Jun 2012

To cite this article: Kai Niebert & Harald Gropengieser (2012): Understanding and communicating climate change in metaphors, Environmental Education Research, DOI:10.1080/13504622.2012.690855

To link to this article: http://dx.doi.org/10.1080/13504622.2012.690855

Pergamon

Learning and Instruction 11 (2001) 331–355
www.elsevier.com/locate/learninstruc

"Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena

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Abstract
An account of conceptual change within the domain of thermal physics is described. In particular, difficulties of students in making an ontological change in the concept of heat is examined. While the overall goal of this research is to document microgenetically the process of conceptual change that takes place as students learn thermal physics, this paper describes the specific role of metaconceptual teaching. It is argued that metaconceptual teaching that addresses the fact that students and scientists may use the same terms for different conceptual referents and that scientific conceptions can account for everyday ones, helps to effect the targeted ontological changes. The pedagogical success of integrating the scientific and the everyday view is consistent with young adolescents' difficulties with a relativistic epistemology in which scientific and everyday views are presented as valid alternatives. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Conceptual change; Everyday knowledge; Scientific knowledge; Thermal phenomena

1. Introduction

Is conceptual change in science learning evolutionary or revolutionary? Different researchers have answered the question differently. Carey (1986), for example, views science learning as theory change, and thus revolutionary, whereas Gunstone and Mitchell (1997), for example, view it as evolutionary, resulting from accretion of information, rather than paradigm shift. Does conceptual change involve the replacement of one conception (the learner's pre-instruction, "naive," or "everyday"

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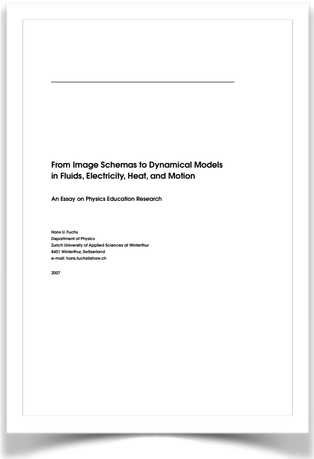
PII: S0959-4752(01)00030-5



From Image Schemas to Dynamical Models in Fluids, Electricity, Heat, and Motion

An Essay on Physics Education Research

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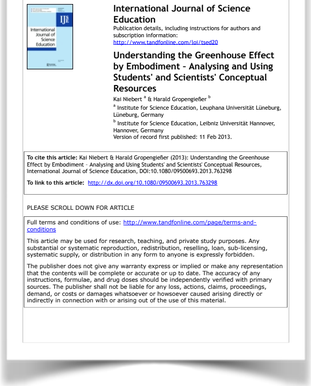
2007



International Journal of Science Education
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsed20

Understanding the Greenhouse Effect by Embodiment - Analysing and Using Students' and Scientists' Conceptual Resources

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Version of record first published: 11 Feb 2013.

To cite this article: Kai Niebert & Harald Gropengießer (2013): Understanding the Greenhouse Effect by Embodiment - Analysing and Using Students' and Scientists' Conceptual Resources, International Journal of Science Education, DOI:10.1080/09500693.2013.763298

To link to this article: http://dx.doi.org/10.1080/09500693.2013.763298

International Journal of Science Education
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713753393

On the Roots of Difficulties in Learning about Cell Division: Process-based analysis of students' conceptual development in teaching experiments

Tania Reinisch [a]; Harald Gropengießer [a]
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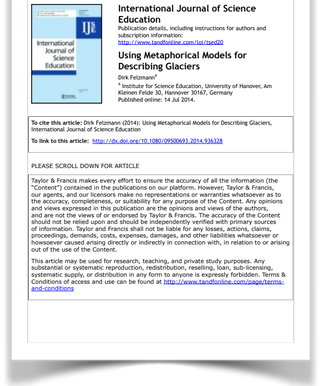
Online Publication Date: 01 January 2007
To cite this Article: Reinisch, Tania and Gropengießer, Harald (2007) 'On the Roots of Difficulties in Learning about Cell Division: Process-based analysis of students' conceptual development in teaching experiments', International Journal of Science Education, 29:10, 1247 — 1266
To link to this article: DOI: 10.1080/09500690701394716
URL: http://dx.doi.org/10.1080/09500690701394716



International Journal of Science Education
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsed20

Using Metaphorical Models for Describing Glaciers

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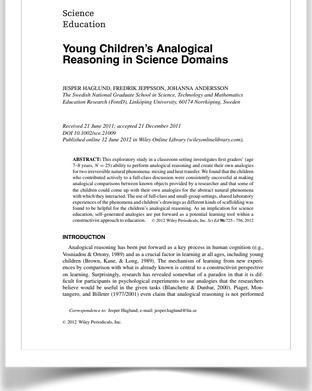
Published online: 14 Jul 2014.

To cite this article: Dirk Felzmann (2014): Using Metaphorical Models for Describing Glaciers, International Journal of Science Education

To link to this article: http://dx.doi.org/10.1080/09500693.2014.936328



Science Education

Young Children's Analogical Reasoning in Science Domains

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Received 21 June 2011; accepted 21 December 2011
DOI 10.1002/sce.21009
Published online 15 June 2012 in Wiley Online Library (wileyonlinelibrary.com).

ABSTRACT: This exploratory study in a classroom setting investigates first graders' (age 7–8 years, *N* = 25) ability to perform analogical reasoning and create their own analogies for two irreversible natural phenomena: mixing and heat transfer. We found that the children could successfully perform all of the following: spontaneously create and express their own analogical comparisons between known objects provided by a researcher and that some of the children could come up with their own analogies for the abstract natural phenomena with which they interacted. The use of full-class and small-group-setting, shared laboratory experiences of the phenomena and children's drawings as different kinds of scaffolding was found to be helpful for the children's analogical reasoning. As an implication for science education, self-generated analogies are put forward as a potential leaning tool within a constructivist approach to education. © 2012 Wiley Periodicals, Inc. Sci Ed 96:775–796, 2012

INTRODUCTION

Analogical reasoning has been put forward as a key process in human cognition (e.g., Vosniadou & Ortony, 1989) and as a crucial factor in learning at all ages, including young children (Brown, Kane, & Long, 1989). The mechanism of learning from new experiences by comparison with what is already known is central to a constructivist perspective on learning. Surprisingly, research has revealed somewhat of a paradox in that it is difficult for participants in psychological experiments to use analogies that the researchers believe would be useful in the given tasks (Blanchette & Dunbar, 2000). Piaget, Montangero, and Billeter (1977/2001) even claim that analogical reasoning is not performed

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Zeitschrift für Didaktik der Naturwissenschaften, Jg. 5, Heft 2, 1999, S. 57-77

Z. DN

HARALD GROPENGIEßER

Was die Sprache über unsere Vorstellungen sagt. Kognitionslinguistische Analyse als Methode zur Erfassung von Vorstellungen: Das Beispiel Sehen

Was ist also Wahrheit? Ein bewegliches Heer von Metaphern, Metonymien, Anthropomorphismen, kurz eine Summe von menschlichen Relationen, die poetisch und rhetorisch gesteigert, übertragen, geschmückt wurden und die nach langem Gebrauch einem Volke fest, kanonisch und verbindlich dünken.

Friedrich Nietzsche

Zusammenfassung:
Oftbeherrschte werden Vorstellungen durch mündliche oder schriftliche Befragung der entsprechenden Meinungsträgergruppe erhoben. Hier wird ein völlig anderer Weg eingeschlagen: Es werden sprachliche Ausdrücke wie Redensarten und feststehende Wendungen, geflügelte Worte und Sprichwörter zu einem Thema (hier: Sehen) als Untersuchungsmaterial herangezogen. Da diese etablierten Metonymien und Metaphern weiten strukturierte innere Bilder und die Grundlagen des Denkens und Handelns beeinflussen, wird ein idealtypisches Cognitives Modell (ICM) des Sehens entworfen, unter anderem zeitspezifischen Fällen. Anschließend werden Alltagsvorstellungen zum Sehen formuliert und mit einem einem anderen Untersuchung vergliche. Der Vergleich zeigt die Gültigkeit dieser kognitionslinguistischen Analyse.

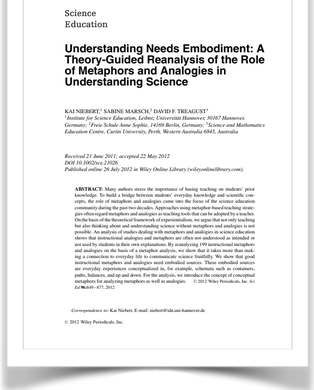
Abstract:
Probing understanding and conceptualization of certain topics is commonly done with interviews as research tools. In this article a totally different methodology is employed, i. e. cognitive linguistic analysis. The method is adapted for the needs of research in science education. Conventional expressions like idioms and phrases used to talk about seeing and vision are investigated. These expressions yield a system of metonymies and metaphors closely related to bodily experience. The metonymies and metaphors converge on an idealized cognitive model (ICM) including prototypical and nonprototypical cases. In addition everyday conceptions of seeing are formulated and compared to the results of a different investigation, thus validating the cognitive linguistic approach.

1. Theoretischer Rahmen

Kognition ist verkörpert

Was die Sprache über unsere Vorstellungen sagt, kann ein in einem theoretischen Rahmen verwendet werden, in dem das Verhältnis von Sprache und Kognition dargestellt und ihr gemeinsamer metaphorischer Charakter erkennbar und fällich wird. Gestützt auf die kognitionslinguistische Erkenntnistheorie und Neurobiologie, auf Wissenssoziologie und vor allem Kognitionslinguistik werden zugehend von der Gewiss unseres kognitiven Systems zunächst die Begriffe der Metapher und der Metonymie erklärt. Es werden dann Klassen von Vorstellungen unterschieden und es wird gezeigt, weshalb Sprache grundsätzlich etwas über Vorstellungen sagen kann.

Aus kleinsten Anfängen entwickelt sich unser Gehirn und damit auch unser mentales System. Wesentliche Leistungen werden nun möglich: Es gelingen immer mehr und vollkommenere Handlungen und kognitive Unterscheidungen. Die Bewegungen und Wahrnehmungen sind dabei für die Entwicklung des kognitiven Systems prägend. Normale Entwicklung hängt von normaler Erfahrung und normaler Interaktion ab (Rakoff, Schwartz & Jones) 1991, 9961). Aus solchen körperlichen Erfahrungen erwachsen die Strukturen unser kognitiven Systems, die Kategorien, die Begriffe oder simbanseder die Vorstellungen. Zwar sind unsere kognitiven



Science Education

Understanding Needs Embodiment: A Theory-Guided Reanalysis of the Role of Metaphors and Analogies in Understanding Science

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Received 21 June 2011; accepted 22 May 2012
DOI 10.1002/sce.21026
Published online 26 July 2012 in Wiley Online Library (wileyonlinelibrary.com).

ABSTRACT: Many authors stress the importance of basing teaching on students' prior knowledge. To build a bridge between students' everyday knowledge and scientific concepts, the role of metaphors and analogies came into the focus of the science education community during the past two decades. Approaches using metaphor-based teaching strategies often regard metaphors and analogies as teaching tools that can be adopted by a teacher. Such approaches are based on the assumption that metaphors and analogies are easy to use, but also thinking about and understanding science without metaphors and analogies is not possible. An analysis of studies dealing with metaphors and analogies in science education shows that instructional analogies and metaphors are often not understood as intended or not used by students in their own explanations. By reanalyzing 199 instructional metaphors and analogies on the basis of a metaphor analysis, we show that it takes more than making a connection to everyday life to communicate science fruitfully. We show that good instructional metaphors and analogies are embedded in a web of ideas that students have on everyday experiences conceptualized in, for example, schemata such as containers, paths, balances, and up and down. For the analysis, we introduce the concept of conceptual metaphors for analyzing metaphors as well as analogies. © 2012 Wiley Periodicals, Inc. Sci Ed 96:449–477, 2012

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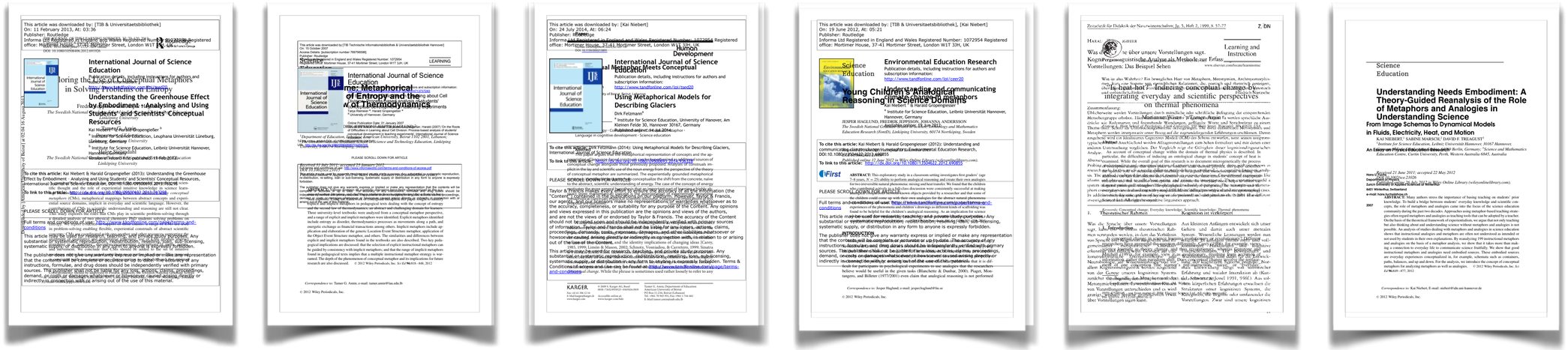
EMBODIED UNDERSTANDING OF SCIENCE CONCEPTS



How can embodied cognition be used as a framework for the design of external representations?

RESEARCH DESIGN

teaching experiments with 118 students (secondary schools/undergraduates, 16-21y) in groups of 2-3

Sample

	topic	students' conceptions (teaching experiments)	scientists' conceptions (text analysis)
microcosm	**cell division**	**48 secondary school students** (16 triads), (15–16 yrs.)	**Campbell et al. (2008)**
microcosm	**neurobiology**	**13 undergraduate students** (5 dyads, 1 triad; 19–24 yrs.)	**Campbell et al. (2008)**
macrocosm	**carbon cycle**	**39 secondary school students** (9 triads, 6 dyads, 17–19 yrs.)	**IPCC (2013)**
macrocosm	**greenhouse effect**	**18 secondary school students** (2 triads, 6 dyads, (17–19 yrs.)	**IPCC (2013)**

RESEARCH DESIGN

teaching experiments with 118 students (secondary schools/undergraduates, 16-21y) in groups of 2-3

Analysis

1. Identification of conceptual metaphors (CM) from published studies

Metaphor analysis (Schmitt, 2000); e.g. Dividing Is Becoming More

2. Defining learning demand by comparing scientists' and students CMs

e.g. Understand that cell division consists of division and enlargement: Reflect division schema

3. Design and evaluate external representations (teaching experiments)

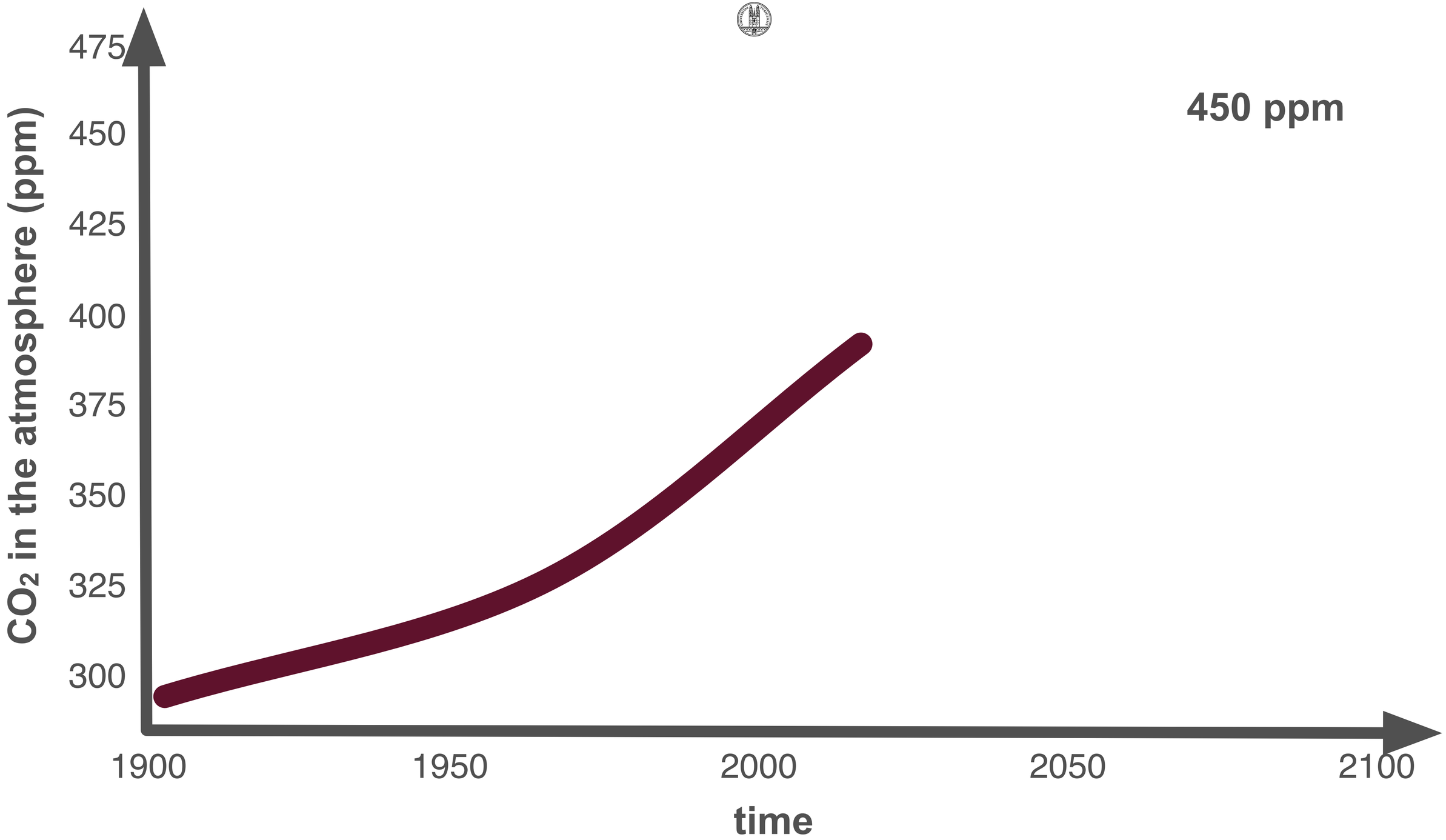
e.g. Reflect the division of a sheet of paper as a representation of the division schema

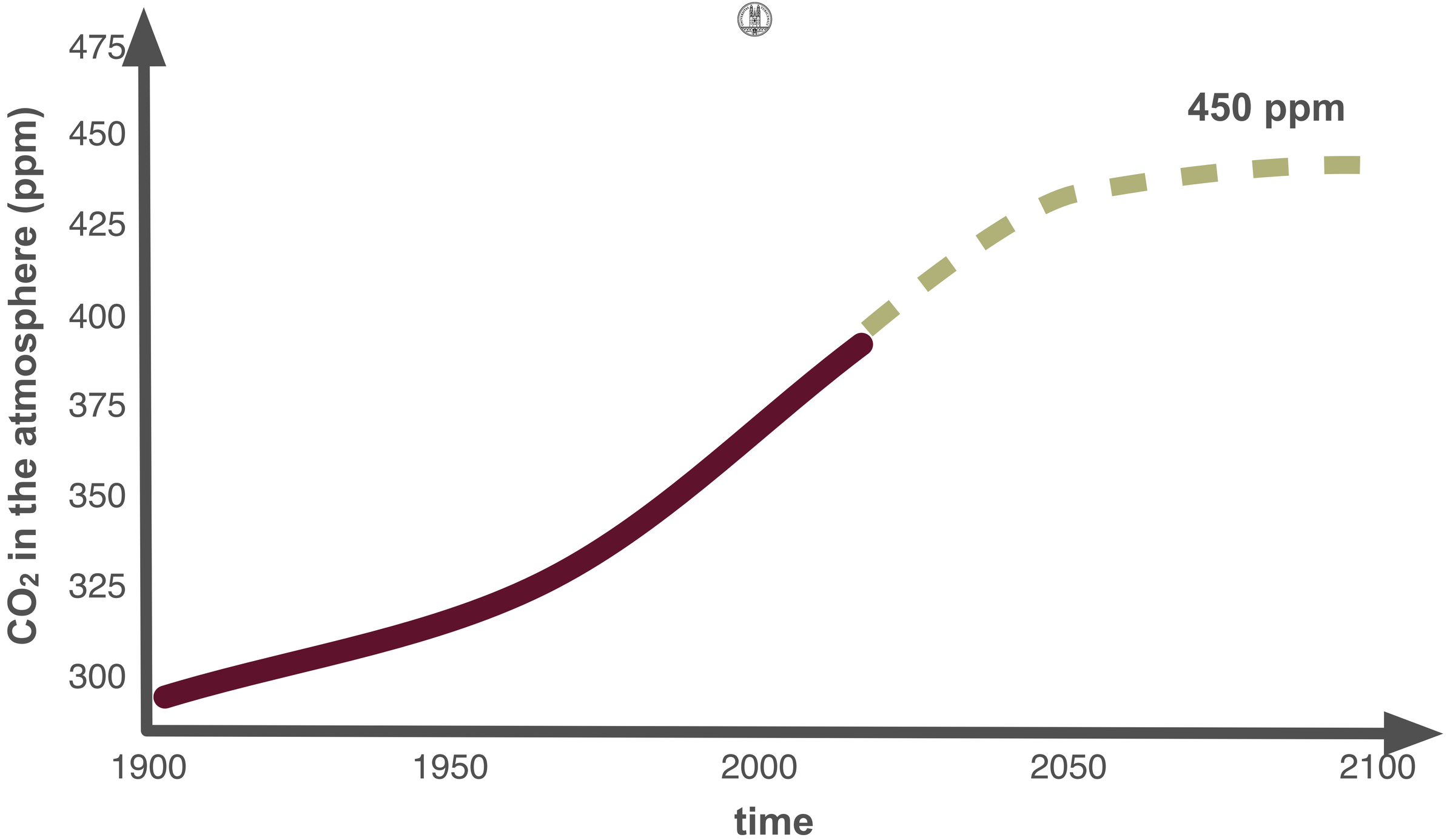
BOUNDARIES OF THE MESOCOSM

Microcosm ⟵ **Mesocosm** ⟶ **Macrocosm**

Lower boundary	*Upper boundary*
seconds *(heartbeat)*	***decades*** *(lifetime)*
millimetre *(hair: 0,1 mm)*	***kilometre*** *(horizon: 20 km)*
v = 0 *(rest)*	***v = 10 m/s*** *(runner)*
a = 0 *(steady motion)*	***a = 10 m/s2*** *(runner)*
gram *(ping-pong ball)*	***ton*** *(tree, elephant, rock)*
0 °C *(freezing point)*	***100 °C*** *(boiling of water)*

see also: Vollmer, G. (1984).
Mesocosm and objective knowledge.


475
450
425
400
375
350
325
300
CO_2 in the atmosphere (ppm)
450 ppm
1900
1950
2000
2050
2100
time


475
450
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325
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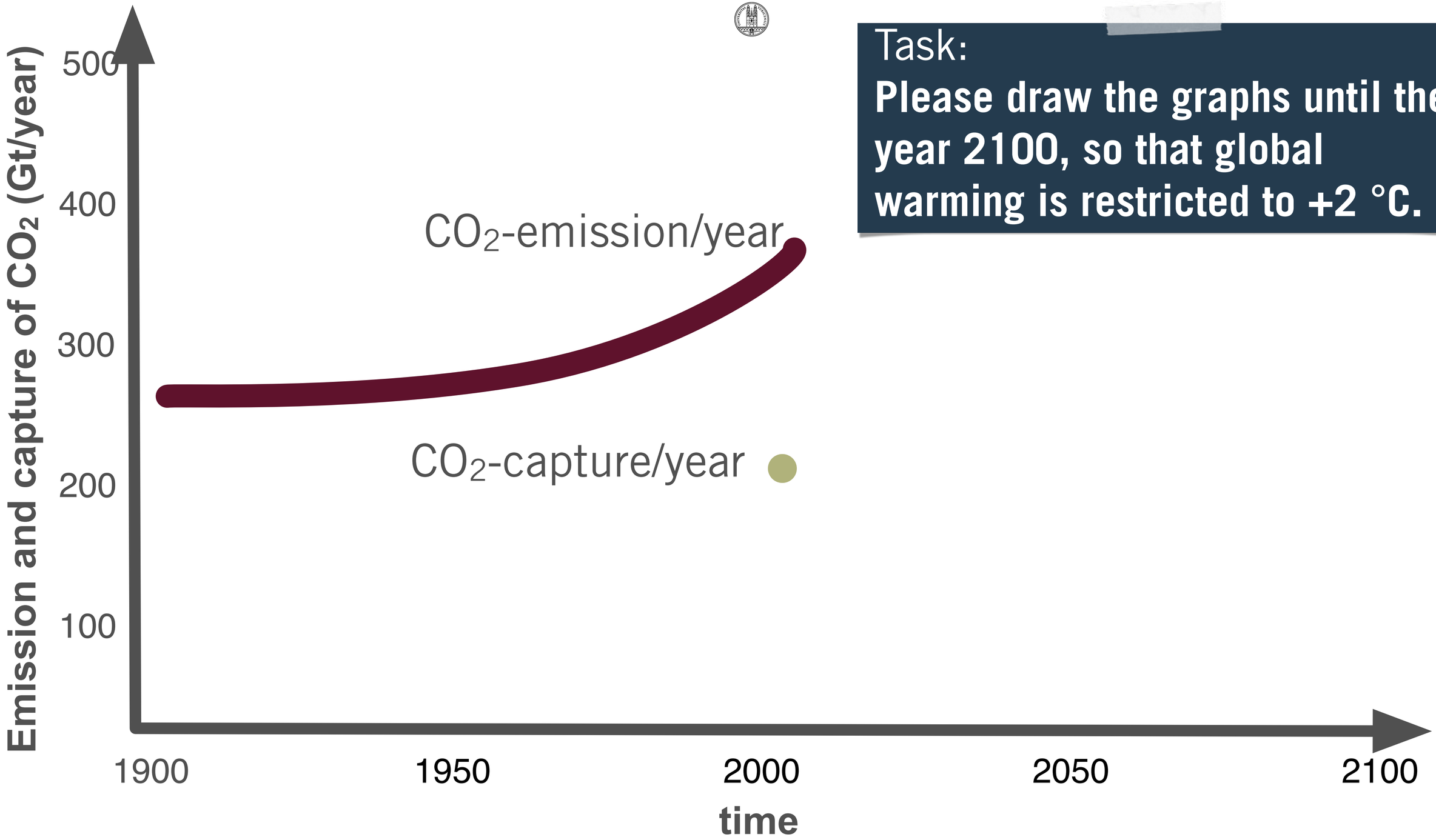
CO_2 in the atmosphere (ppm)
450 ppm
1900
1950
2000
2050
2100
time

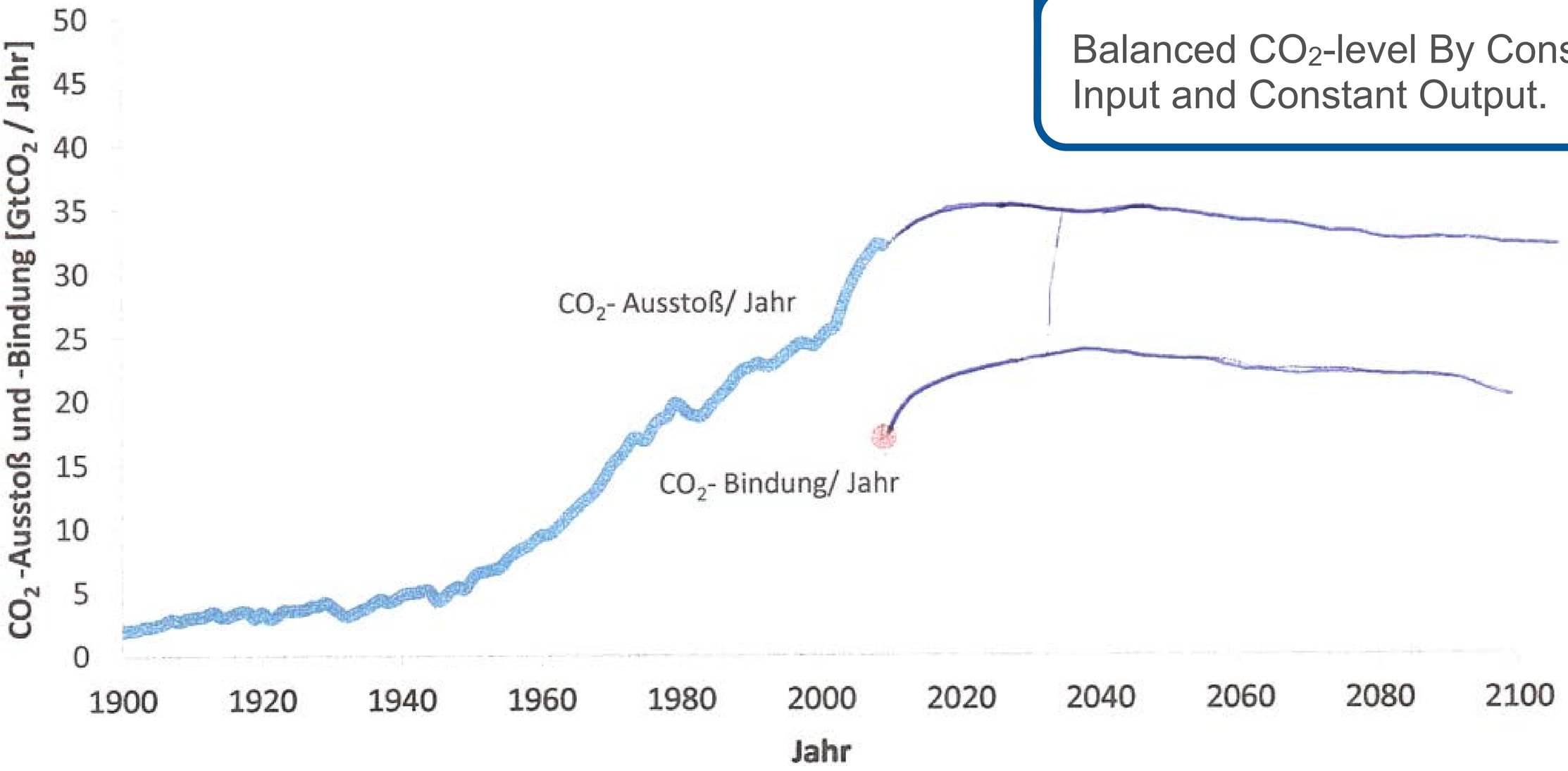


Task:

Please draw the graphs until the year 2100, so that global warming is restricted to +2 °C.

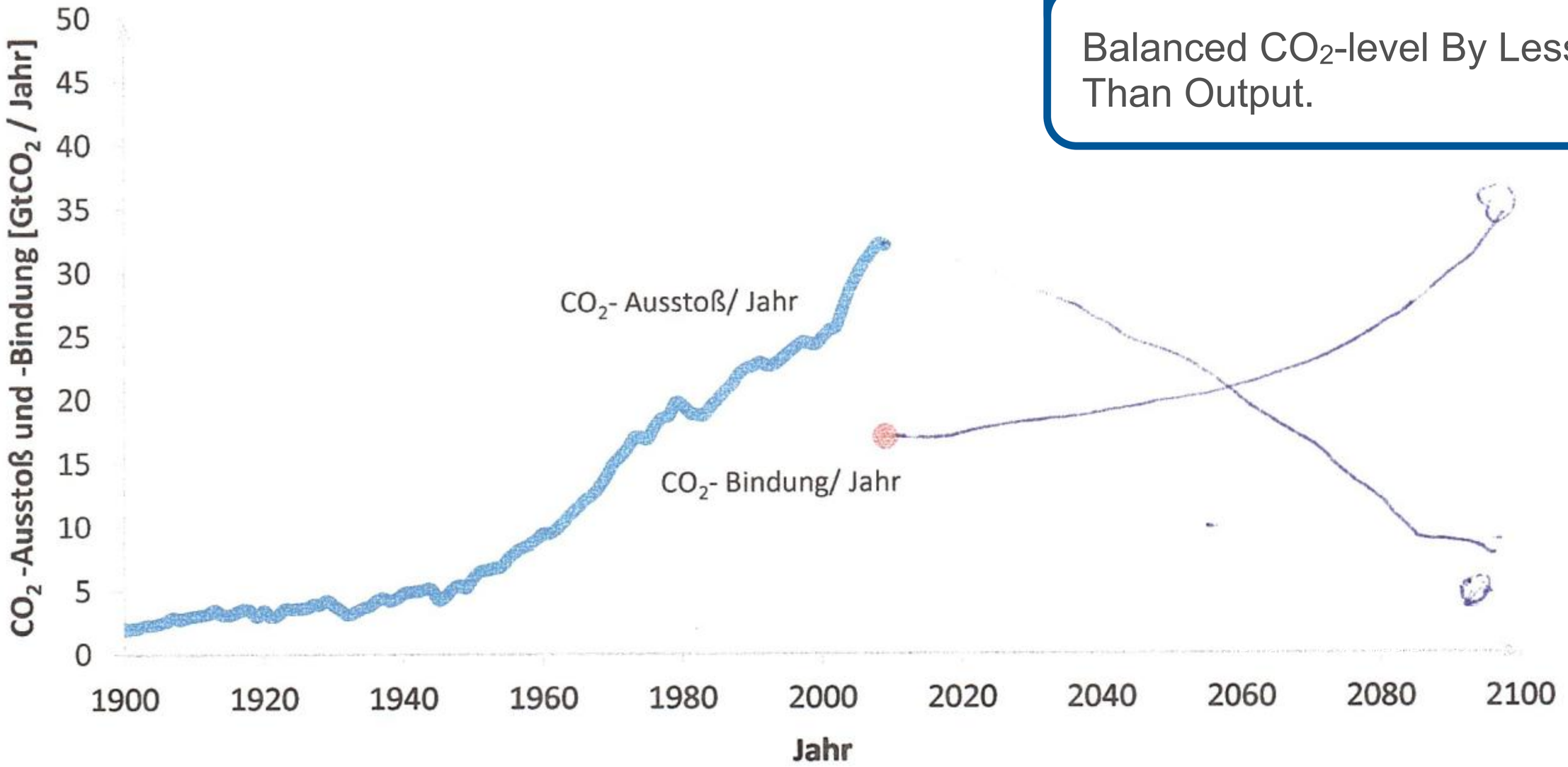
Students' CM

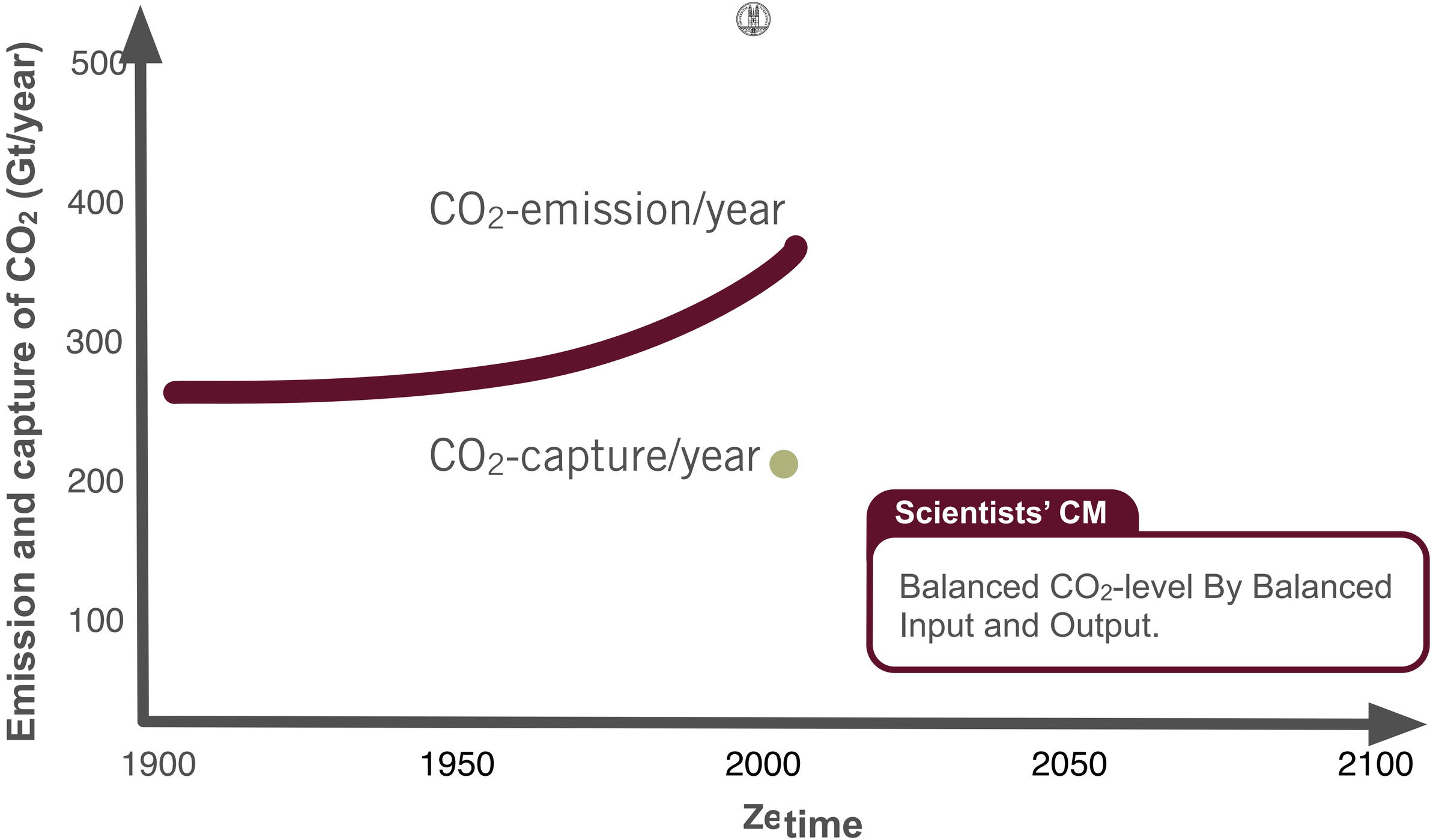
Balanced CO_2-level By Constant Input and Constant Output.



Students' CM

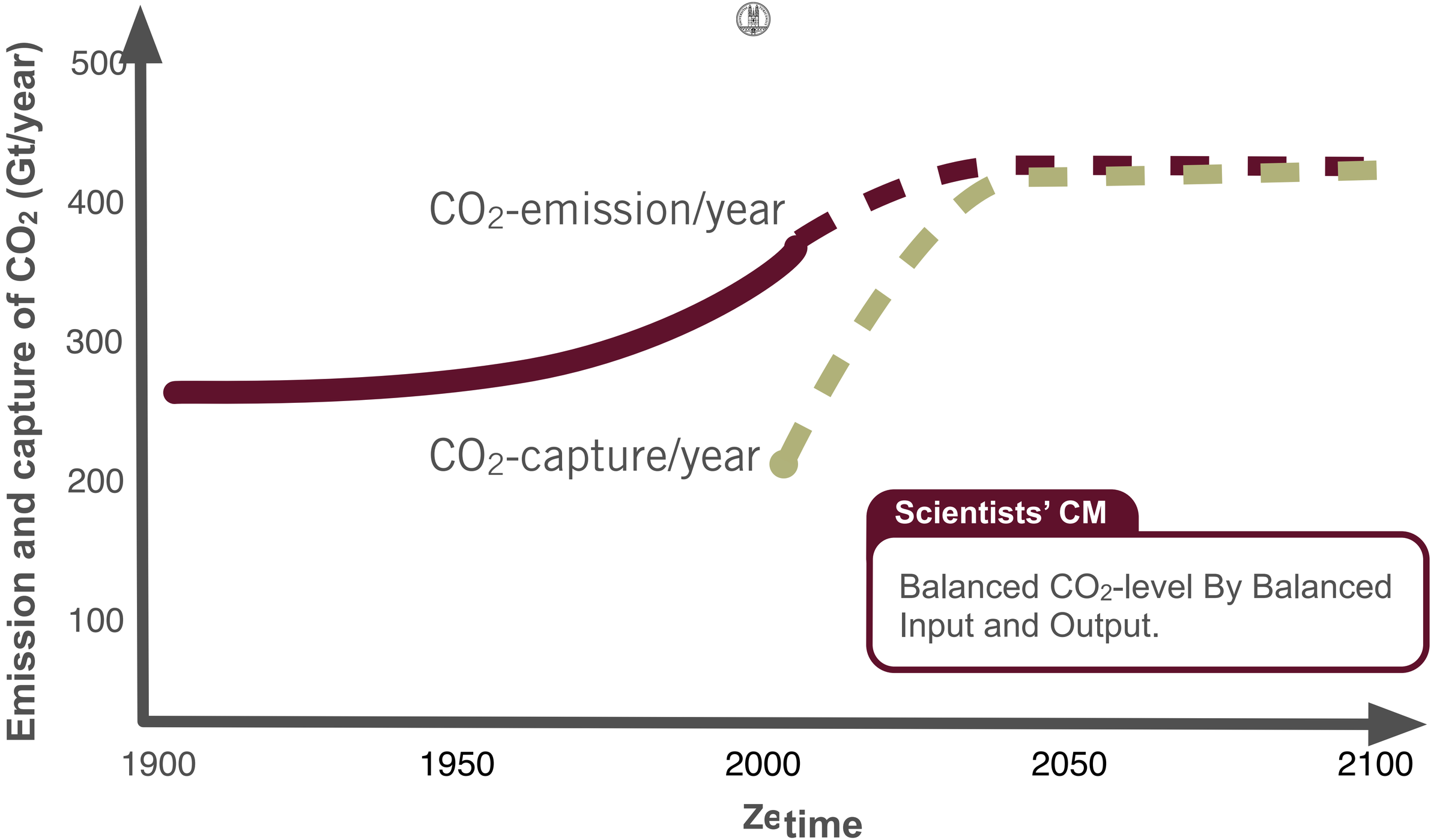
Balanced CO_2-level By Less Input Than Output.





Scientists' CM

Balanced CO_2-level By Balanced Input and Output.


Emission and capture of CO_2 (Gt/year)
500
400
300
200
100
CO_2-emission/year
CO_2-capture/year
1900
1950
2000
2050
2100
Ze time
Scientists' CM
Balanced CO_2-level By Balanced Input and Output.

84 %

highly qualified MIT-graduates violate the law of conservation of matter

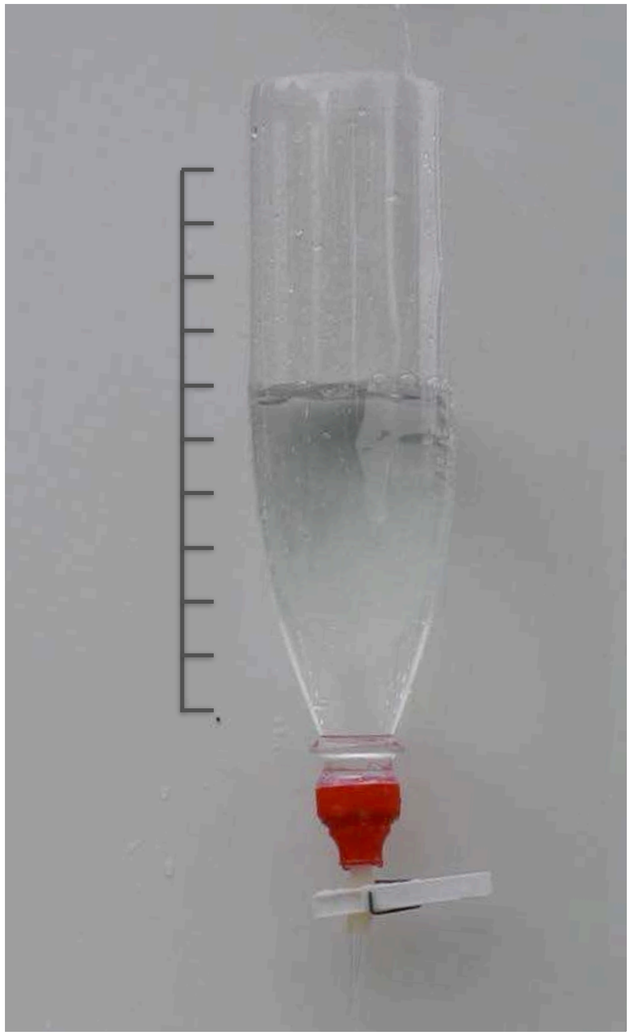
Sterman, J. D., & Sweeney, L. (2007).

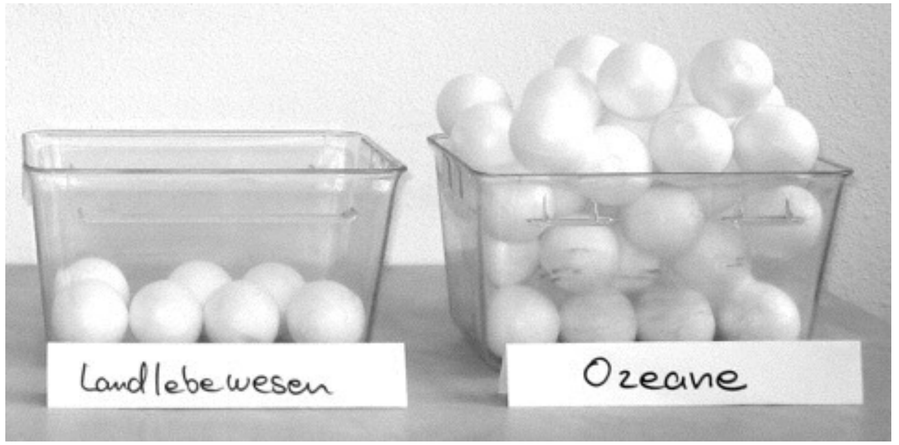
(57% for science faculty staff at Leuphana University)
(59 % on Conceptual Change Conference 2014)

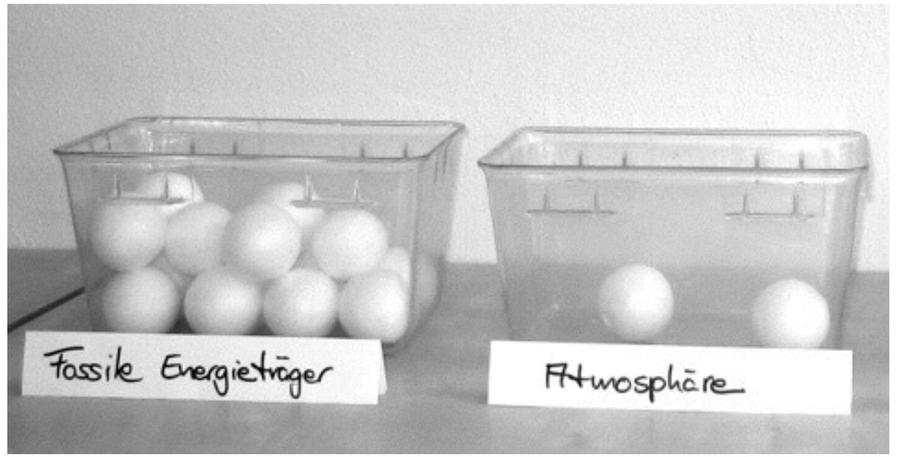
CONCEPTUAL METAPHORS OF STUDENTS AND SCIENTISTS

Topic	Students' Conceptual Metaphors	Scientists' Conceptual Metaphors
Microbial growth	Dividing Is Becoming More Growth By Division	Dividing Is Becoming More Dividing Is Becoming Smaller Growth By Division and Enlargement
Signal conduction	Travel Time Depends On Range	Travel Time Depends On Range Travel Time Depends On Speed of Signal
Greenhouse effect	Warming By More Input Warming By Less Output Atmosphere Is Container: CO_2 Is Top of Container/CO_2 Is Cloud, CO_2 Destroys Boundary	Warming By Shifted Equilibrium Atmosphere Is Container: CO2 Fills Container
Carbon Cycle	Balanced CO_2-level By Constant Input Balanced CO_2-level By Less Input than Output	Balanced CO_2-level By Balanced Input and Output

REFLECTING EMBODIED CONCEPTIONS

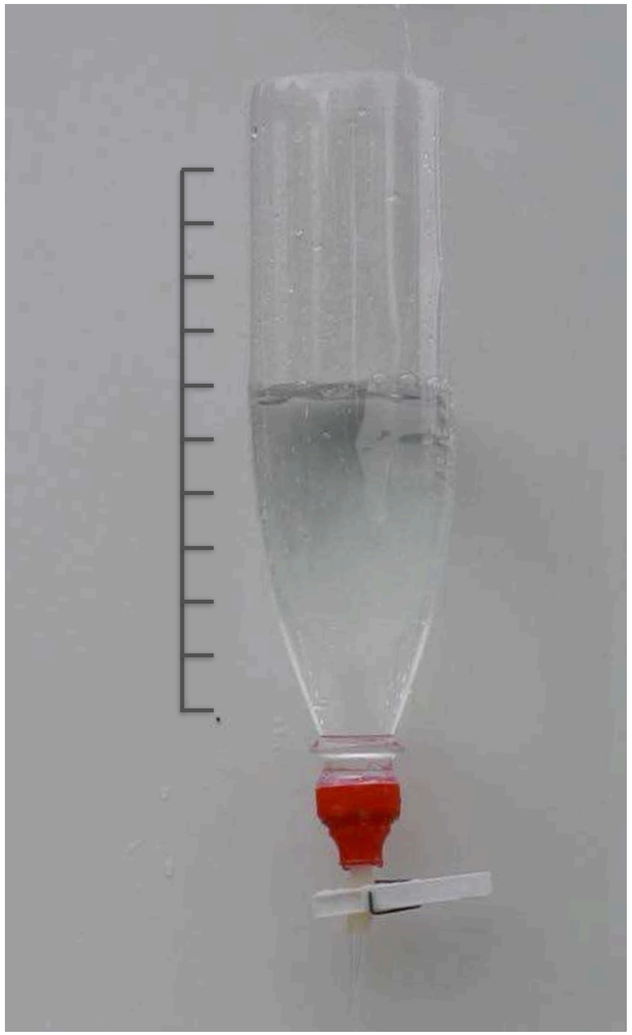


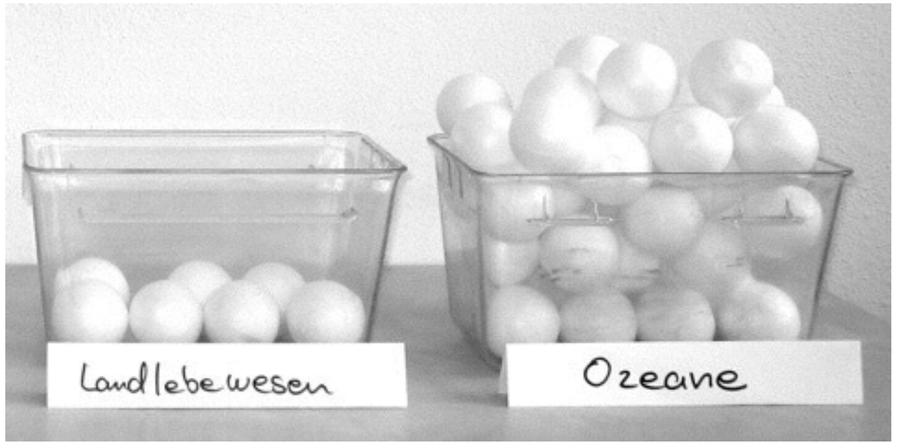


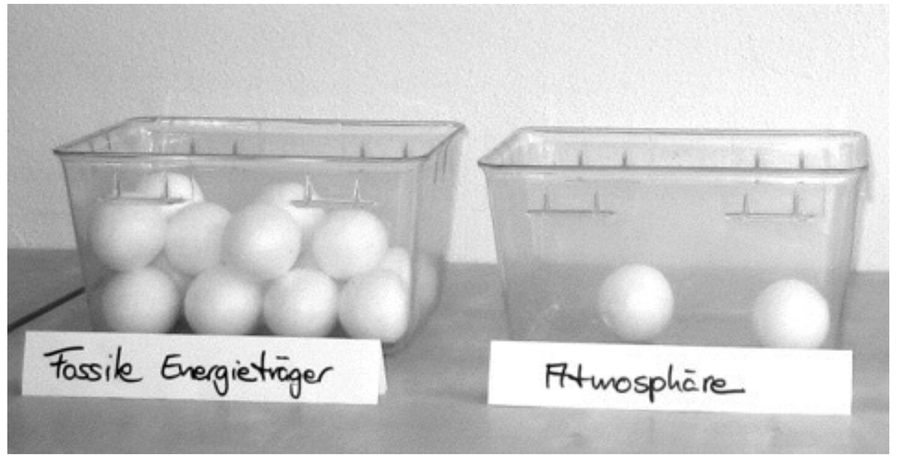


E

REFLECTING EMBODIED CONCEPTIONS

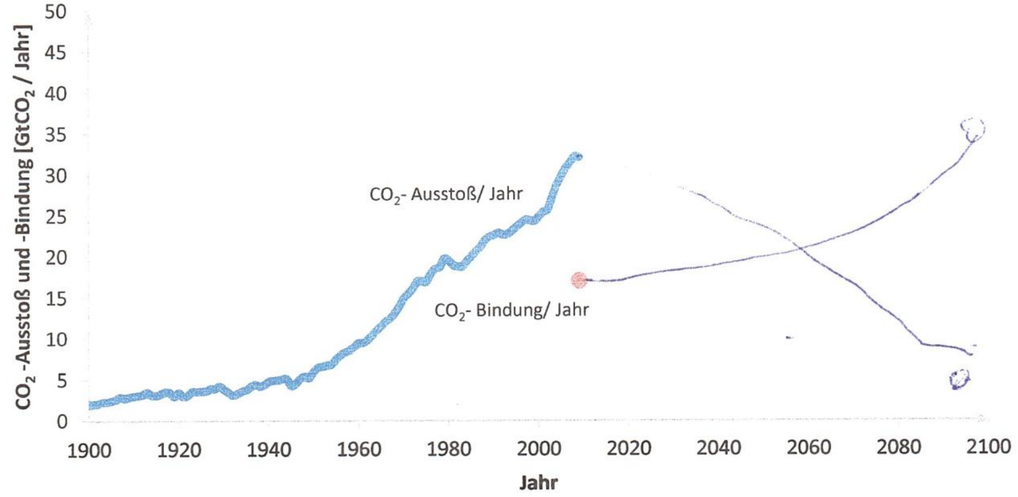


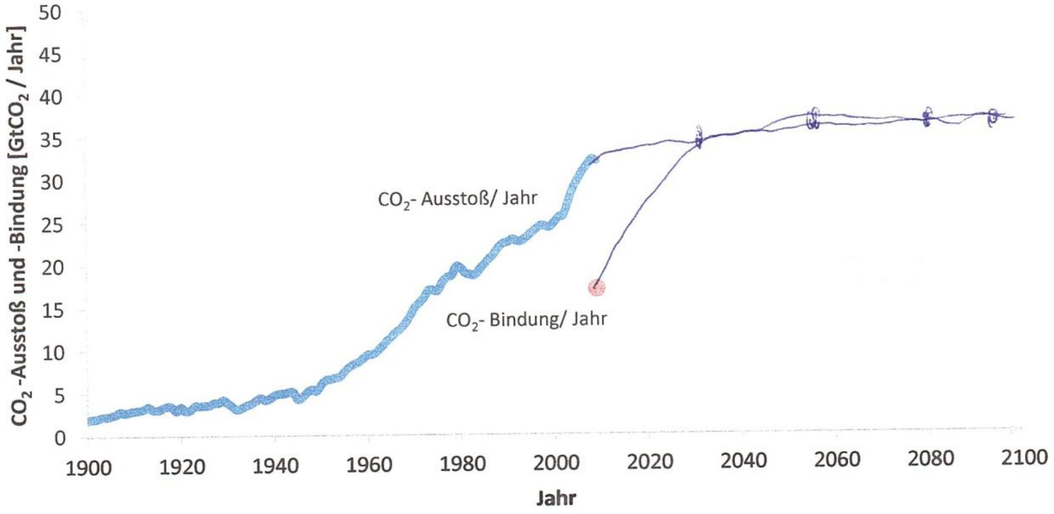




E

WHILE WORKING WITH THE ER ‚BALANCE SCHEMA‘





The CO_2 emissions are the inflowing water, the outflowing water determines the removal. The beaker is the atmosphere. We have a balance when input and output are the same.

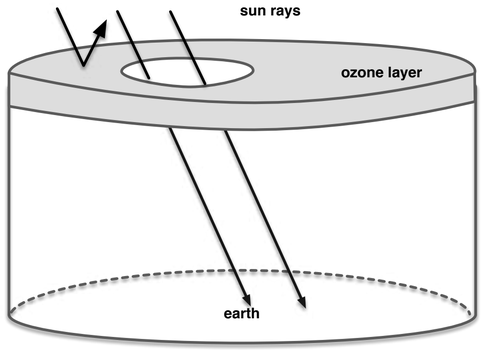
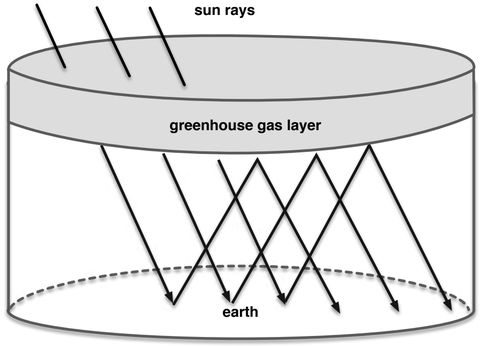
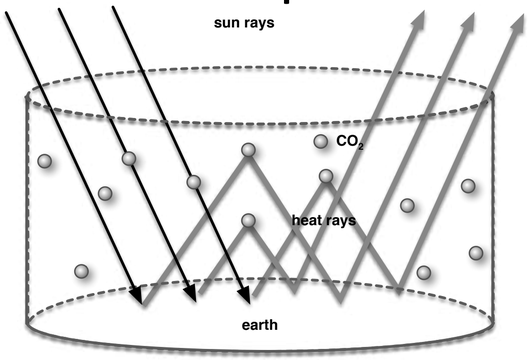
[…]

If I emit less CO_2 than is removed, then at some point there is no CO_2 in the atmosphere and we get the next ice age.

(Hannes)

FROM **LEARNING DEMAND** TO **EXTERNAL REPRESENTATIONS**

Topic	Learning demand	External representations
Microbial growth	*Understand that cell division consists of division and enlargement: Reflect division schema*	*ER 'Tearing paper': Divide a sheet of paper as a representation of the division schema*
Saltatory signal conduction	*Understand that myelin makes the action potential jump from node to node: Reflect travel-schema*	*ER 'Toppling Dominos': Domino-brick and straw model*
Greenhouse effect	*Understand the role of CO_2 in climate change: Experience the properties of CO_2 and reflect container schema* *Understand the energy flows in global warming: Reflect balance schema*	*ER 'Greenhouse effect' to afford experience on the role of CO_2 in global warming, reflect on the absence of ozone* *ER 'Reflect balance schema' to disclose and work with an implementation of the combined container- and balance schemata, reflect its mapping to the dynamic equilibrium within the greenhouse effect*
Carbon cycle	*Understand that a constant CO_2-level means a balance in emission and removal: Reflect balance schema.*	*ER 'Reflect balance schema' to disclose and work with an implementation of the combined container- and balance schemata, reflect its mapping to the dynamic equilibrium within the carbon cycle*

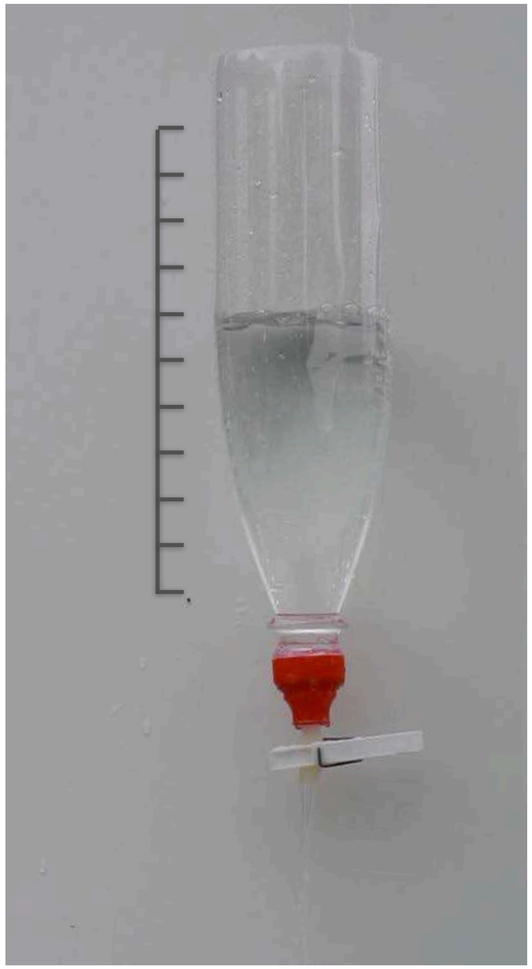
	Everyday Conception		Scientific Conception
Container	**Warming By Ozone Hole**  *"CO_2 makes a hole into the ozone-layer. More sun rays enter the atmosphere and the earth warms up"*	**Warming by Greenhouse Effect**  *"Sun rays come through the CO_2 -layer into the atmosphere. They are transformed into heat and captured"*	**Warming by Greenhouse Atmosphere**  *"CO_2 is evenly distributed in the atmosphere. More CO_2 shifts the radiative equilibrium."*
	Ozone is boundary	CO_2 is boundary	CO_2 is content
	CO_2 destroys boundary	CO_2 is permeable one way only	CO_2 is impermeable for heat rays
Balance	**Warming by more input.**	**Warming by less output.**	**Warming by new equilibrium**

AFFORDING EXPERIENCE ON THE GREENHOUSE EFFECT

I thought that the ozone hole is responsible for warming. But it cannot be. I mean, we have no ozone layer here and it is warming anyway.

(Ann)

REFLECTING EMBODIED CONCEPTIONS



The idea ‘Warming By More Input’ was what we initially thought. But it cannot be, because this would mean the ozone hole is involved—and it isn’t. The CO_2 stores the heat, so it must be ‘Warming By Less Output’.

But if it is less output, more and more heat is captured in the atmosphere. The temperature would rise to infinity. I think it must be this »New Equilibrium«.

Yes, CO_2 stores heat and gives it away again. But the more CO_2 is in the atmosphere, the more heat is stored. It is like my pocket money: Until my birthday, I got 10€ a week—and spent everything. Now, I get 15€ every week, and there is nothing left zoo, too. But now I can afford to go to the cinema in every week.

CONCLUSIONS

- When understanding is embodied, external representations of micro- and macrocosmic concepts should map into mesocosm.
- Analysing conceptions on the level of conceptual metaphors helps to reveal learning demand.
- Embodied cognition helps to make learning demand fruitful:
  a) missing experience -> ERs that afford experience
  b) false mapping of embodied conception -> ERs that disclose image schemata

Thank you.

Download paper:

Kai Niebert & Harald Gropengiesser (2015): Understanding Starts in the Mesocosm: Conceptual metaphor as a framework for external representations in science teaching, International Journal of Science Education
DOI: 10.1080/09500693.2015.1025310

Download presentation:

www.kainiebert.de